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Changes of Electrical Impedance Characteristic of Pork in Heating Process

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Abstract. The purpose of this study is to investigate a change of electrical impedance characteristics of meat in heating process. In our experiments, pork fillets were heated at constant temperature of 50, 60, 70 and 100 ℃ for 3, 6 and 9 minutes, and we measured their electrical impedance and cooking loss. In order to express measured electrical impedance, equivalent circuit analysis is utilized using modified Hayden model, which consists of by intracellular resistance R_i and extracellular resistance R_e, and cell membrane capacitance C_m. From the experiment, R_i and R_e increased and C_m decreased while the cooking loss increased during the heating process. Both changes of the electrical impedance and cooking loss are more pronounced at higher heating temperature. Especially, the relationship between R_e and cooking loss was remarkable. Therefore, electrical impedance spectroscopy (EIS) can evaluate physical property changes of meat during heating.

Keywords: Electrical impedance spectroscopy, heating, pork, cooking loss

1. Introduction

Electrical impedance spectroscopy (EIS) is a measure of the electrical impedance of materials as a function of frequency. The change of impedance with frequency offers a lot of useful information of materials. This method, which is one of physiological assessments of materials, is a very simple and quick method to perform compared to other techniques. Therefore, EIS has been used to evaluate the physical characteristics of various materials. In EIS study, equivalent circuit model plays an important role to relate the measured impedance to the physical properties of the materials. Hayden et al. [1] proposed an equivalent circuit model, namely Hayden model, to describe an equivalent circuit model of physiological tissue. Hayden model has been used to discuss about changes in cellular states during the ripening of fruits and heat injury and cold injury of the vegetables. Applications of EIS to meat have also been reported. Damez et al. [2] applied EIS to beef to monitor its aging process with investigating the change of parameters in the equivalent circuit model based on the cell structure. Oliver et al. [3] investigated electrical impedance characteristics of ham to evaluate its quality. Although applications of EIS to meat have been mainly focused on the natural physiological properties, there are few reports to apply EIS on food processing such as heating. An important indicator of heated meat includes cooking loss, which means the amount of the moisture, fat and soluble protein which flowed out of heated meat, and influences eating quality and textures. It is inferred from electrolyte of cooking loss that it affects impedance characteristics. Therefore we investigate a relationship between impedance characteristics and cooking loss. The objective of this study is to investigate the changes in impedance characteristics and to explore potential of EIS as a method to evaluate physical property changes of meat during heating.

2. Electrical Impedance Spectroscopy

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In the EIS study, the impedance of the samples was measured as a function of frequency. The complex impedance has the real part (resistance: R) and the imaginary part (reactance: X);

$$R = |Z|\cos\theta \ , X = |Z|\sin\theta \tag{1}$$

where, θ denotes the phase different. The relationship between R and X is represented as the Cole-Cole plot on the complex plane. Figure 1(a) shows pattern diagram of the biological tissues. At the cellular level, since the capacitance of cell membrane is significantly large, the low frequency of component of the current flows along only the extracellular fluid. However, the high frequency component is able to flow along the intracellular fluid through the cell membrane. These characteristics were represented as the equivalent circuit shown in Fig. 1(b) proposed by Hayden et al. [1]. The Hayden model expresses an accurate semicircle as a Cole-Cole plot. However, the impedance characteristics of meat express a semiellipse as a Cole-Cole plot due to its inhomogeneous tissue. In order to model this pressed semi-circle, constant phase element (CPE) [4] is used instead of capacitance C_m in the modified model (Fig. 1(c)). The impedance of CPE Z_{CPE} is calculated by the equation below;

$$Z_{CPE} = \frac{1}{(j\omega)^p T} \tag{2}$$

Where, ω denotes the angular frequency, and CPE constant, T denotes magnitude of CPE. CPE exponent p takes a value within the range of 0 through 1. Figure 2 shows the example of the Cole-Cole plot of the modified model. As described, the pressed Cole-Cole plot can be described by changing a value of p. In this study, we applied modified model for the meat during heating. The parameters of the equivalent circuits are estimated with complex non-linear least squares curve-fitting [5]. Here, the unit of T changes with the values of p, thus, the unit of T must be fixed for the accurate comparison of capacitive component of cell membrane. The apparent C_m is calculated by the equation below;

$$C_m = T^{\frac{1}{p}} (R_e + R_i)^{\frac{1-p}{p}} \ . \tag{3}$$

In this study, apparent C_m was obtained by the values of each parameter in the modified model to equation (3) and defined as cell membrane capacitance.

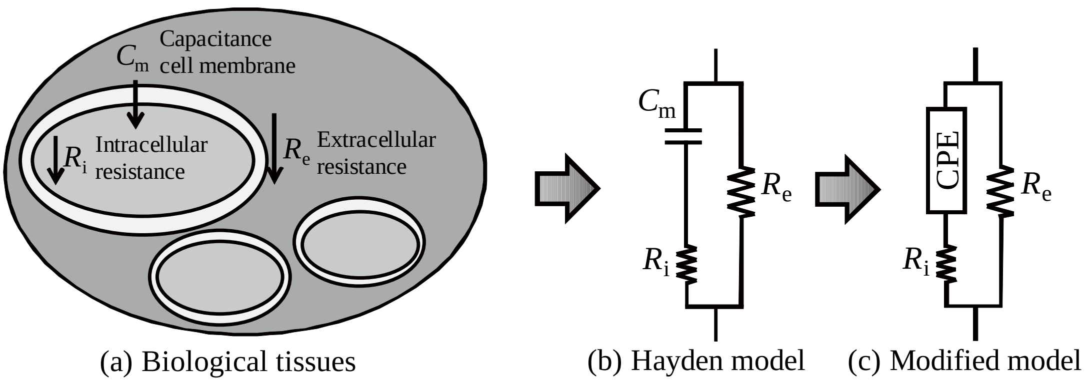

Fig. 1: Pattern diagram of the biological tissues and Equivalent circuit models for biological tissue.

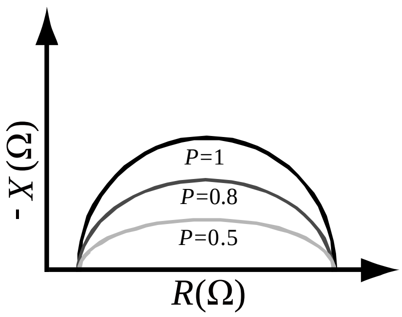

Fig. 2: Example of the Cole-Cole plot of the modified model

3. Experimental Procedure

3.1. Heating Method

In this study, the pork fillets (thickness: 10mm) were used for experiment. Figure 3 shows the schematic diagram of heating system. As a method of heating, the sample in the plastic bag was immersed in temperature-controlled water. The samples were heated at constant temperature of 50, 60, 70 and 100 ℃ for 3, 6 and 9 minutes. Each temperature was kept constant by the thermo couple and controller. The samples were immediately cooled after heating in iced water for sufficient time.

3.2. Cooking loss

Cooking loss is calculated by the equation below;

$$\text{Cooking loss} = 100 \times \left(1 - \frac{W_h}{W_r}\right) (\%) \quad . \tag{4}$$

Where, W_h denotes the weight of the heated sample, W_r denotes the weight of the raw sample. Difference in the weight of raw and heated samples was defined as a cooking loss.

3.3. Impedance Measurement

Figure 4 shows the schematic diagram of EIS measurement system. Magnitude of electrical impedance $|Z|$ and phase angle θ of the samples were measured by using impedance analyzer with needle electrodes (insertion length: 5mm, distance between electrodes: 34mm) at frequency ranging from 100 Hz to 15 MHz.

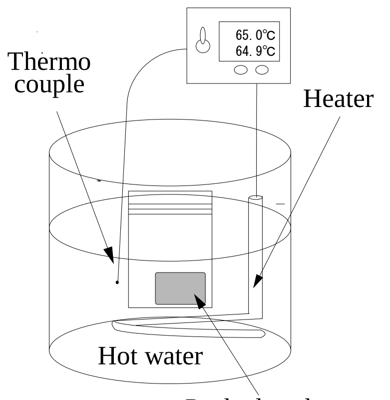

Fig. 3: Schematic diagram of heating system

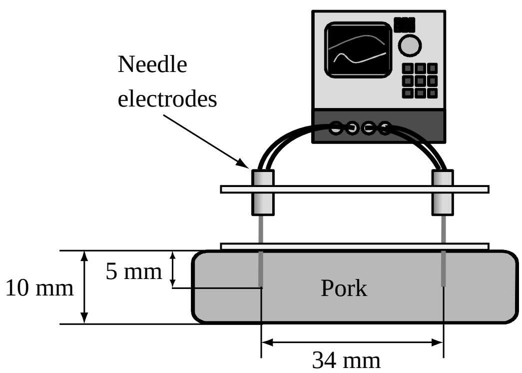

Fig. 4: Schematic diagram of EIS measurement system

4. Results and Discussion

The relationship between heating time and each equivalent circuit parameters were shown in Fig. 5. As heating process, the extracellular resistance R_e and the intracellular resistance R_i increased, and Cell membrane capacitance C_m decreased. Moreover, the amount of changes of R_e, R_i and C_m were larger at the higher heating temperature. Figure 6 shows the changes of cooking loss during heating. Cooking loss that means the amount of the moisture, fat and soluble protein which flowed out of heated sample, increased with higher heating temperature. Martens et al. [6] explained thermal denaturation temperature of the myofibrillar proteins (myosin; 40-60℃, actin; 66-73℃) and collagen shrinkage temperature (56-62℃). Palka and Daun [7] explained that cooking loss is relevant to the thermal denaturation of myofiber proteins. As shown in fig. 7, R_e is positively correlated with cooking loss (correlation coefficient is 0.875). Therefore, we consider that the increase of R_e were caused by the effluence of electrolysis solution. Collagen is a substance which compose the cell membrane. From Fig. 5, it seems that the temperature at which collagen start shrinking is corresponded with that of C_m and R_i start changing. Thus, it was considered that the decreases of C_m and increase of R_i were closely related with the injury of cells and leakage of intracellular fluid from the inside of cells.

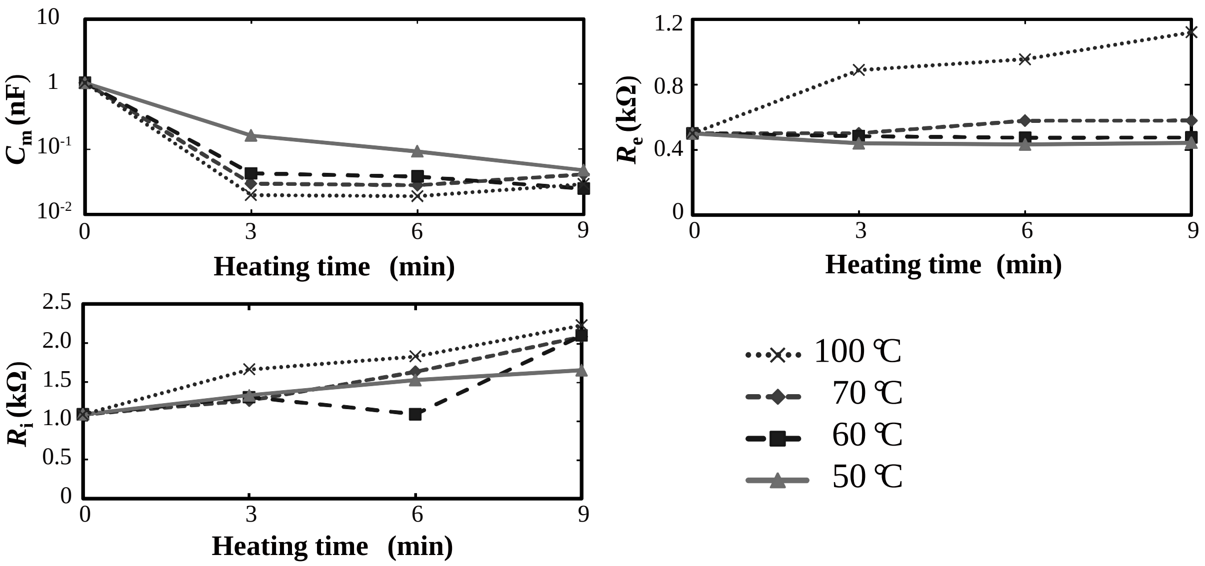

Fig. 5: Change of each equivalent circuit parameters to heating time

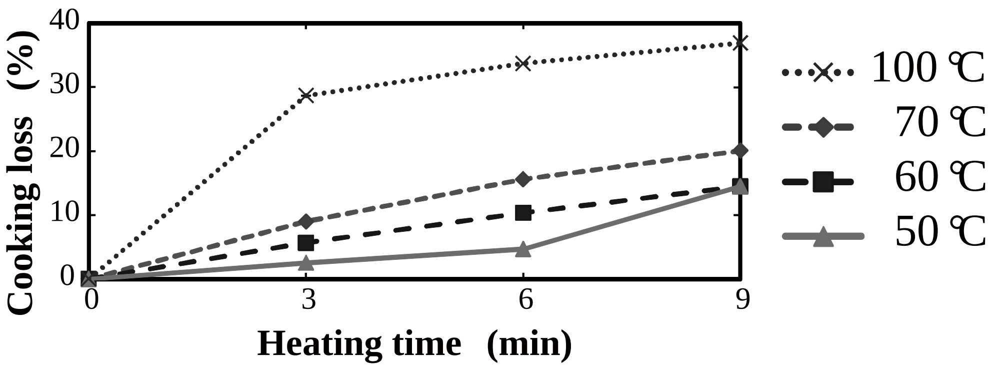

Fig. 6: Change of cooking loss to heating time

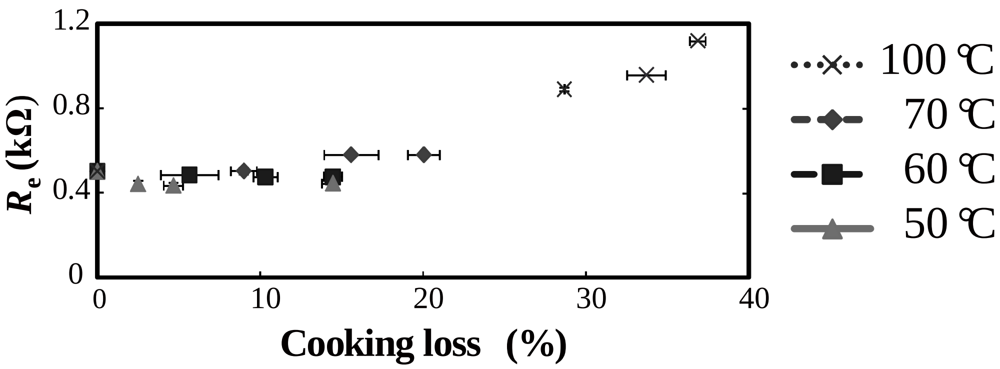

Fig. 7: Change of R_e to cooking loss

5. Conclusion

In our experiments, the pork fillets were heated at different constant temperature, and we measured electrical impedance and cooking loss of heated sample. Equivalent circuit analysis was used with modified model to measured electrical impedance. In the results, cooking loss increased with higher heating temperature. Intracellular resistance R_i and extracellular resistance R_e increased, cell membrane C_m decreased during heating process. A high correlation between cooking loss and extracellular resistance R_e was observed. Therefore this study suggests EIS can evaluate physical property changes of meat during heating.

6. References

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